

Magnetic fields of wires and forces on moving charges

AP Physics 2 (algebra-based) · Lesson

Quick answer: A moving charge or a current produces a magnetic field, and a magnetic field pushes sideways on other moving charges. A long wire gives $B = \mu_0 I / 2\pi r$, a charge feels $F = qvB \sin \theta$, and a wire feels $F = BIL \sin \theta$. The force never speeds a charge up.

Level: AP Physics 2 (algebra-based) · **Curriculum:** AP P2 Unit 12

What creates a magnetic field around a wire?

Every moving charge produces a magnetic field. In a wire, the drifting charges add up to a field that circles the wire. The field gets weaker with distance and stronger with more current. The unit of magnetic field is the tesla (T), where $1 \text{ T} = 1 \text{ N}/(\text{A}\cdot\text{m})$.

Formula

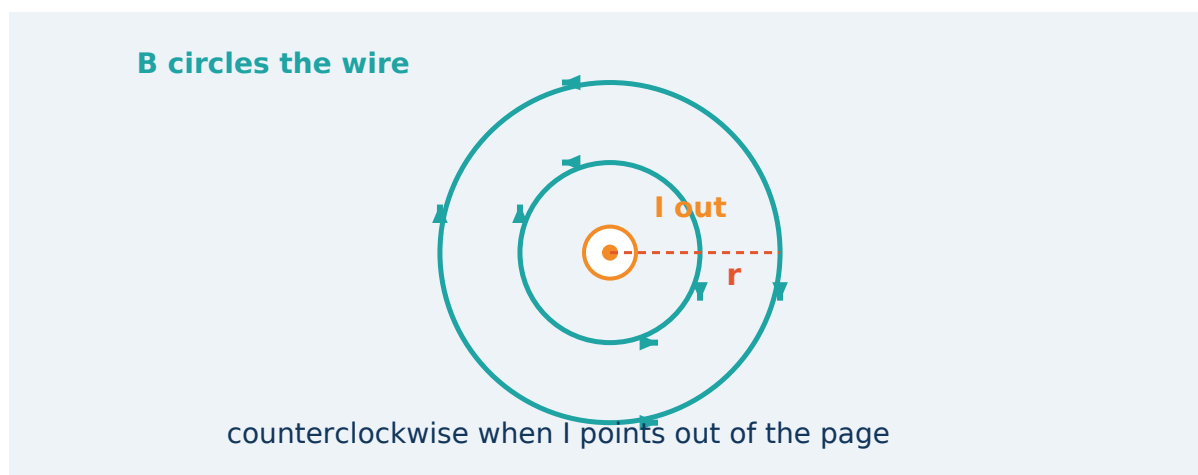
$$B = \mu_0 I / (2\pi r)$$

B = field strength (T), $\mu_0 = 4\pi \times 10^{-7} \text{ T}\cdot\text{m}/\text{A}$, I = current (A), r = perpendicular distance from the wire (m).

Definition

A **magnetic field** (B) is the region of influence of moving charges and magnets. Its strength is defined through the force it exerts: $B = F / (qv)$ for a charge moving at right angles to the field. Its direction is the way a compass needle points.

Point the thumb of your right hand along the current. Your fingers curl in the direction of the field lines. A wire with current out of the page has counterclockwise field lines.



Field strength falls as $1/r$, so the circles are drawn further apart far from the wire.

Worked example

Wanjiru in Nairobi measures a cable carrying 20 A. Find the field 5.0 cm from the cable.

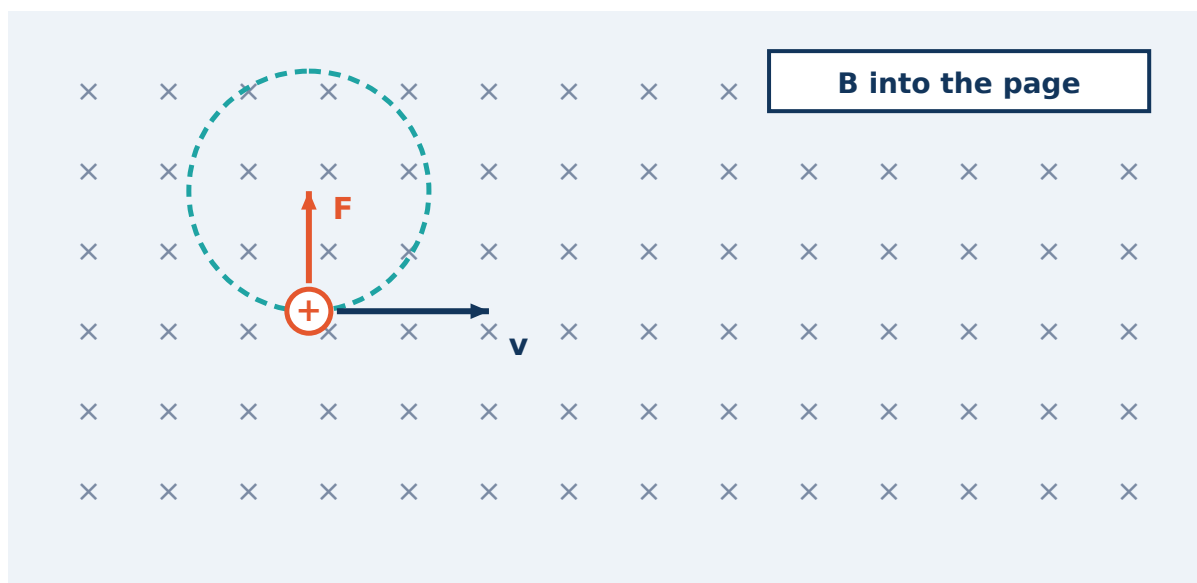
$B = \mu_0 I / 2\pi r = (4\pi \times 10^{-7})(20) / (2\pi \times 0.050) = \mathbf{8.0 \times 10^{-5} \text{ T}}$. This is about the same size as the Earth's field, which is why a compass near a cable can be misled.

How does a magnetic field push a moving charge?

Key law

The magnetic force on a charge q moving with speed v at angle θ to a field B is $F = |q|vB \sin \theta$. The force is perpendicular to both v and B . Use the right-hand rule: fingers along v , curl towards B , thumb gives the force on a positive charge. Reverse it for a negative charge.

Because the force is always sideways, it does no work. The speed stays constant and only the direction changes. A charge moving at right angles to a uniform field travels on a circle, where the magnetic force supplies the centripetal force: $qvB = mv^2/r$, so $r = mv / (qB)$.



A positive charge entering the field to the right is pushed upward, and then curves round counterclockwise.

Worked example

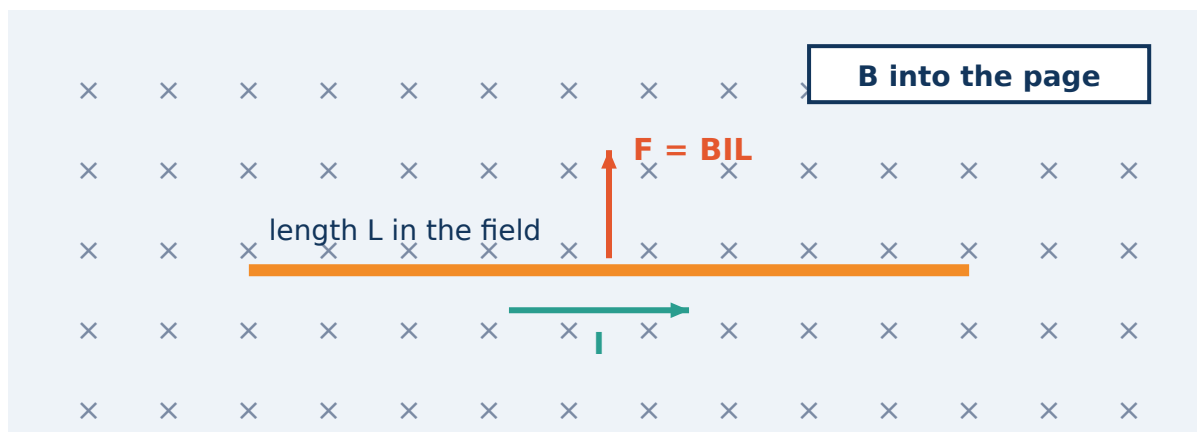
An electron moves at 2.0×10^6 m/s at right angles to a field of 1.5 mT. Find the force and the radius of its path.

$F = evB = (1.6 \times 10^{-19})(2.0 \times 10^6)(1.5 \times 10^{-3}) = \mathbf{4.8 \times 10^{-16} \text{ N}}$. Then $r = mv / (eB) = (9.11 \times 10^{-31})(2.0 \times 10^6) / [(1.6 \times 10^{-19})(1.5 \times 10^{-3})] = \mathbf{7.6 \text{ mm}}$.

What force acts on a current-carrying wire?

A current is a flow of moving charges, so a wire in a field feels the sum of the forces on them. For a straight length L carrying current I at angle θ to the field, $F = BIL \sin \theta$. The direction

follows the same right-hand rule, with the thumb pointing along the conventional current.



With B into the page and current to the right, the force on the wire points up.

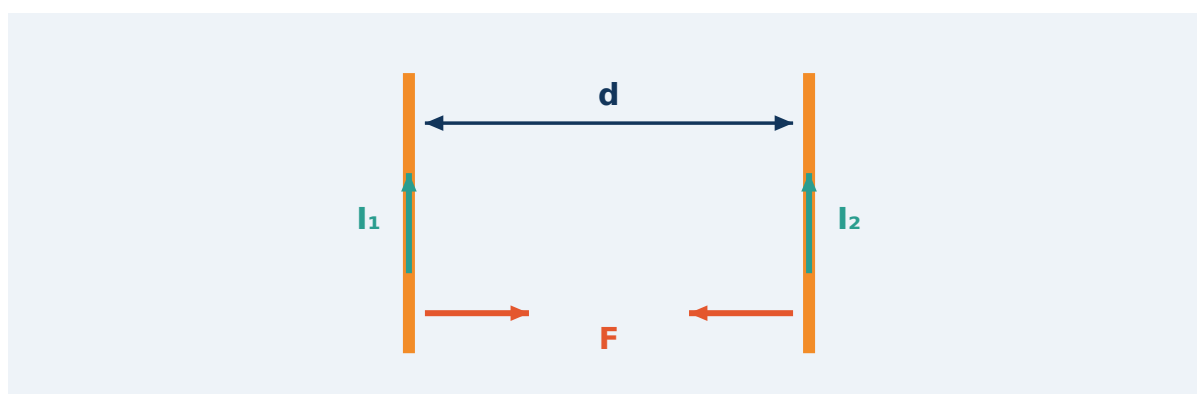
Situation	Magnitude	Direction
Moving charge in a field	$F = q vB \sin \theta$	perpendicular to v and B
Wire in a field	$F = BIL \sin \theta$	perpendicular to I and B
Field of a long wire	$B = \mu_0 I / 2\pi r$	circles the wire (right-hand grip)
Two parallel wires, per metre	$F/L = \mu_0 I_1 I_2 / 2\pi d$	attract if currents are parallel

Common mistake

A magnetic force does not act on a charge at rest, and it is zero when the velocity is parallel to the field. Students often push the particle along the field lines. The force is always sideways to them.

How do two parallel wires push or pull each other?

Each wire sits in the field of the other, so each feels a force. Currents in the same direction attract and currents in opposite directions repel. The force per metre is $F/L = \mu_0 I_1 I_2 / (2\pi d)$.



Parallel currents attract: each wire is pulled towards the other with an equal force.

Worked example

Two wires 4.0 cm apart carry 10 A and 15 A in the same direction. Find the force per metre.

$$F/L = (4\pi \times 10^{-7})(10)(15) / (2\pi \times 0.040) = 7.5 \times 10^{-4} \text{ N/m, attractive.}$$

Lina's tip

Draw the field directions as dots (out) and crosses (in) first. Then apply one right-hand rule at a time, and check that your answer is perpendicular to both v (or I) and B .

Key points to remember

- Field of a long wire: $B = \mu_0 I / (2\pi r)$, with $\mu_0 = 4\pi \times 10^{-7} \text{ T}\cdot\text{m/A}$
- Force on a charge: $F = |q|vB \sin \theta$, perpendicular to v and B
- Circular path: $r = mv/(qB)$ for v perpendicular to B
- Force on a wire: $F = BIL \sin \theta$
- Parallel currents attract: $F/L = \mu_0 I_1 I_2 / (2\pi d)$

Magnetic fields of wires and forces on moving charges: frequently asked questions

What is the unit of magnetic field?

The tesla (T), equal to $1 \text{ N}/(\text{A}\cdot\text{m})$. The Earth's field is about $5 \times 10^{-5} \text{ T}$, and a strong laboratory magnet reaches roughly 1 T .

Why does a magnetic force do no work on a charge?

The force is always perpendicular to the velocity, so there is no component along the motion. The speed and kinetic energy stay constant, and only the direction of travel changes.

When is the magnetic force on a moving charge zero?

It is zero when the charge is at rest, when it moves parallel or antiparallel to the field ($\sin \theta = 0$), or when it has no charge. Maximum force occurs when v is perpendicular to B .

How do you find the direction of the force on a wire?

Point the fingers of your right hand along the conventional current, curl them towards the field, and the thumb gives the force. The force is perpendicular to both the wire and the field.

Why do parallel currents attract?

The field from one wire at the position of the other points so that the force on the second current is towards the first. The result is symmetrical, so each wire pulls the other equally.